THE GEOLOGY OF ECUADOR

Explanatory note for the Geological Map of the Republic of Ecuador (1:500000)

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EXPLANATORY NOTE FOR THE GEOLOGICAL MAP OF THE REPUBLIC OF ECUADOR **(*)** (1:500000)

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ABSTRACT

Brief background information is given regarding the compilation of this map. The geology, including the principal structural elements, are briefly described.

The geological legend is divided into three sections corresponding to three geographical areas: the Coastal Plain, the Andean Range and the «Oriente», or Amazon Basin area.

The metamorphics are the oldest rocks. Palaeozoic sediments are only rarely present in the «Oriente» and eastern foothill regions. The Permian and Triassic periods are apparently not represented. The Jurassic and Cretaceous are characterized in the Coastal Plain area by typical eugeosynclinal basic effusives and in the «Oriente» by marine sediments. During Upper Cretaceous times, marine sediments and volcanics covered the entire country. During the Tertiary a succession of marine shelf and continental sediments and associated volcanics filled depressions in all three geographic regions including the developing intra-Andean graben. During the Quaternary more acidic volcanics blanketed the mountain ranges whilst molassic sediments were deposited in the «Oriente» and marine terraces formed on the Coastal Plain.

The N-S and NNE-SSW faults are typical of Andean tectonism, but E-W transverse faults (probably initiated prior to Andean movements) are an important structural component of the South American continent and are closely related to the development of metallogenic provinces. The effect of the Laramide Orogeny is both considerable and important. Throughout the Tertiary many local but strong orogenic phases persisted, and, towards the close of the Tertiary, continued uplift was associated with volcanic activity. The latter is still continuing.

RESUMEN

Las diferentes etapas de la construcción del mapa son rápidamente descritas. Además, damos una revisión general de la geología y de la estructura del territorio ecuatoriano.

La leyenda geológica está dividida en tres partes correspondientes a tres zonas morfológicas: la Costa, la Cordillera Andina y el Oriente o Cuenca Amazónica.

Un complejo metamórfico parece representar las rocas más antiguas. Los sedimentos paleozoicos afloran solamente en el Oriente y a los pies de las cordilleras orientales. Las rocas del Pérmico y del Triásico no fueron observadas. El Jurásico y el Cretácico están caracterizados en la Costa por las rocas efusivas del tipo eugeosinclinal y en el Oriente por sedimentos marinos. Durante el Cretácico Superior, sedimentos marinos y rocas volcánicas cubrieron el territorio. Durante el Terciario, una sucesión de sedimentos marinos, continentales y neríticos asociados a rocas volcánicas llenaron las depresiones en éstas tres regiones, así también el graben intra-andino. Durante el Cuaternario, rocas volcánicas, generalmente más ácidas, recubrieron las zonas montañosas, mientras tanto los sedimentos de tipo molásico se depositaron en el Oriente y terrazas marinas se formaron en la Costa.

Fallas de orientación Norte-Sur y Norte-Norte-Este son típicas de la tectónica andina. Fallas Este-Oeste, probablemente ya desarrolladas antes de los movimientos andinos, son estructuralmente importantes para el continente Sudamericano y parecen ser responsables de interesantes «metalotectos». Los efectos de la orogenia «Laramide» son fuertes. Durante el Terciario numerosas fases orogénicas, locales pero importantes, modificaron la estructura, y el fin del Terciario está caracterizado por un sobre-levantamiento general, asociado a una fuerte actividad volcánica, cuyos efectos perduran hasta ahora.

RÉSUMÉ

Brève description des différentes étapes de l'élaboration de la carte et aperçu général de la géologie et des structures.

La légende géologique est divisée en trois sections correspondant aux trois entités morphologiques de la République Équatorienne, à savoir : La Plaine Côtière, la Cordillère Andine et l'«Oriente» ou bassin amazonique.

Un complexe métamorphique semble représenter les roches les plus anciennes. Les sédiments paléozoïques sont seulement présents dans l'«Oriente», et aux pieds des chaînes montagneuses orientales. Les roches du Permien et le Trias n'ont pas été rencontrées. Le Jurassique et le Crétacé sont caractérisés dans la Plaine Côtière par des roches effusives du type eugéosynclinal et dans l'«Oriente» par des sédiments marins. Durant le Crétacé Supérieur, des sédiments marins et des roches volcaniques recouvrent tout le territoire. Au Tertiaire, une succession de sédiments marins, continentaux et néritiques associés à des roches volcaniques remplit les dépressions développées sur tout le territoire, y compris le graben intra-andin. Au Quaternaire, des roches volcaniques en général plus acides que les antérieures, recouvrent les régions montagneuses tandis que des sédiments du type molassique se déposent dans l'«Oriente» et des terrasses marines se développent sur la Plaine Côtière.

Des failles d'orientation Nord-Sud et Nord-Nord-Est son caractéristiques de la tectonique andine; des failles d'orientation Est-Ouest, probablement déjà développées avant les mouvements andins, sont d'une importance structurelle pour le continent sud-américain, et semblent avoir développé des métallotectes intéressants. Les effets de l'orogenèse «Laramide» sont considérables. Durant le Tertiaire, de nombreuses phases orogéniques, locales mais importantes, modifient la structure et la fin du Tertiaire est marquée par un soulèvement général associé à une forte activité volcanique dont les effets se continuent encore de nos jours.

INTRODUCTION (*)

This new geological map (Goossens and Pico, 1969) was originally compiled to obtain geological background information for the Mineralogic and Metallogenic Map of the Republic of Ecuador, 1:1000000 (Goossens, 1969). Due to the lack of any map on this scale, the Ecuadorian Service of Geology and Mining has decided to publish this map as six separate sheets both in colour and black and white. Wording on the map is both in Spanish and English. Much of the material used for compilation was obtained from the archives of the Ecuadorian Service of Geology and Mining **(**)**.

Only two geological maps of the Republic of Ecuador have been previously published. The first, at a scale of 1:1000000, is annexed to the book « Geología y Geografia del Ecuador» by Theodor Wolf (1892). The second, at a scale of 1:1500000, was compiled by Walter Sauer (1950). Since these very important works, which were based principally on foot and horseback traverses, many private companies (especially oil companies) have published partial geological studies. Lately, detailed stratigraphical work over sedimentary areas by the Institut Français du Pétrole, together with geological and exploration activities by the Survey of Metallic and Non-Metallic Minerals of the United Nations Development Programme (UNDP), have fundamentally added to the stratigraphical and structural knowledge of the Ecuadorian Republic. Hence the new map does present much recent information. The lack of precision and many errors which remain are due to the scarcity of regional geological information and accurate base maps. The main difficulty, however, is the confusion surrounding geological terminology. Various stratigraphical terms are used by private companies, and as yet no committee or institution has been formed to rationalize stratigraphic correlation and classify the introduction of new names and information. In spite of an attempt at correlation and taking into account the detailed work by Hoffstetter (1956) it was decided for the purpose of this map to separate the stratigraphy into three units, each unit corresponding to a distinctive geographical area i.e. the Coastal Plain, the Andean Range and the Oriente, or Amazon Basin. With a map scale of 1:500000 it has been impossible to represent all the previously described formations. The stratigraphic units as differentiated may represent several formations. Where the word Formation has been used in the legend this does not always imply that it would meet the demands of recognized international classification. Generally, the terminology used is based strictly on lithological field information. Many years of systematic mapping and investigation will be required before the stratigraphy of Ecuador can be more accurately classified. Some formations as now described and known may well be facies of a single formation.

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PHYSICAL FEATURES

Ecuador can be divided into three geographical units (Fig. 1): the Coastal Plain to the west, where altitudes occasionally reach 1000 m above sea-level, the « Oriente » or Amazon Basin to the east where altitudes range from 200 m to 1000 m westwards towards the foothills, and the central Andean Range where altitudes of more than 6000 m are reached, but with average altitudes of between 2000 m and 3000 m for the inhabited valleys. The Ecuadorian section of the Andean Range consists principally of two parallel cordilleras, the easterly« Cordillera Real » and the westerly « Cordillera Occidental ». This division is better marked in the south where a well-defined intra-Andean valley is developed. Because of limited information, the Galapagos Islands are represented by a 1:1000000 insert.

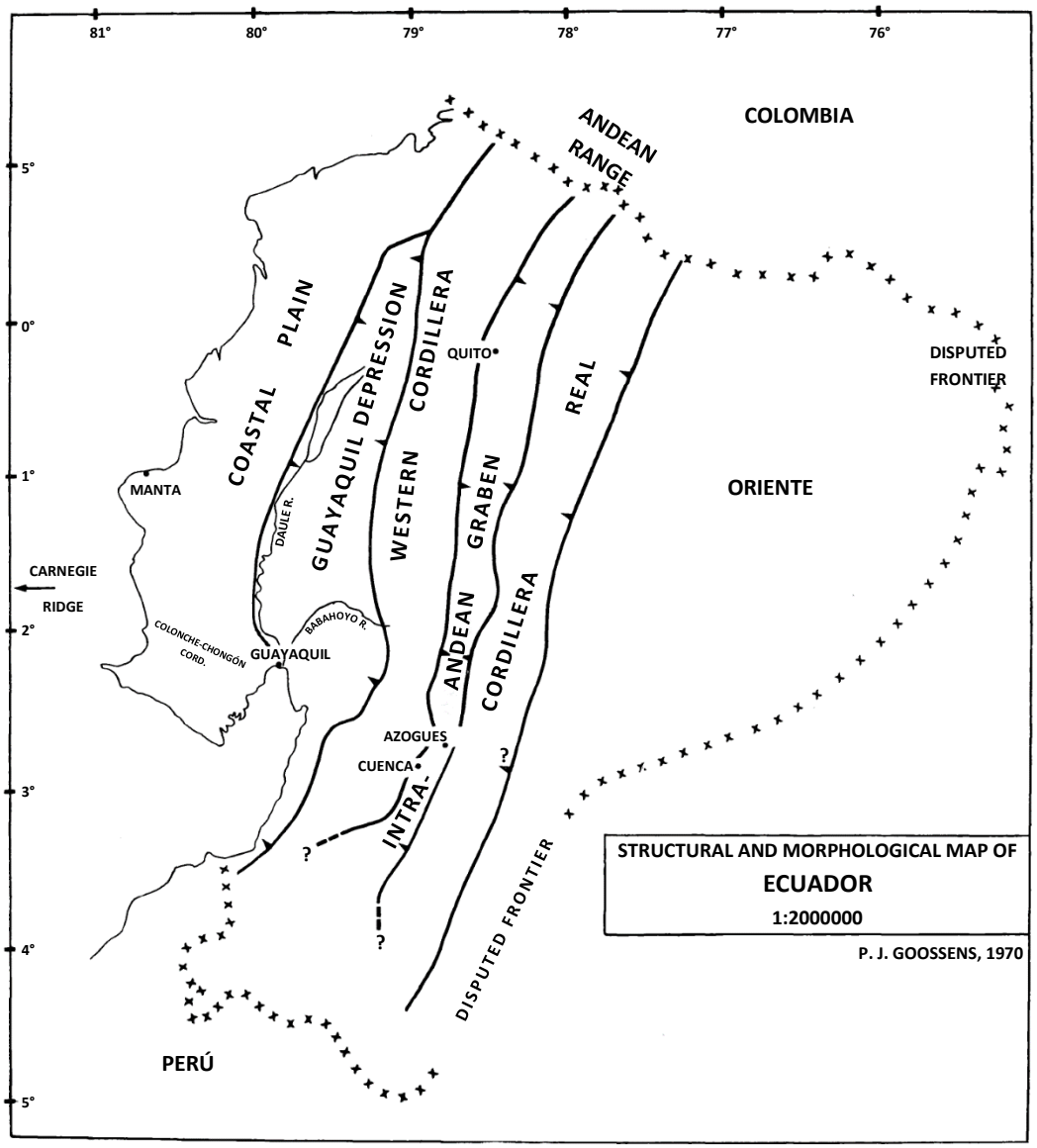


Fig. 1

GENERAL GEOLOGY

The oldest rocks observed are metamorphics, which, particularly in the south of the country, form two parallel belts to the west and east along the Andean foothills. There is almost certainly continuity between these belts in the root zone of the Andes. Various metamorphic grades are represented, ranging from garnet-biotite gneisses to low-grade andalusite-bearing phyllites. However, due to lack of geological information no sub-divisions have yet been made. Future regional and detailed work may allow differentiation of these metamorphics into distinctive orogenic-age belts. Both Precambrian and Palaeozoic rocks may be represented. The oldest sedimentary rocks known are of Palaeozoic age. They outcrop in the « Oriente » along the eastern cordillera and foothills regions where they are of marine facies. Permian and Triassic rocks have never been recognized. The Jurassic sediments, of marine calcareous facies, are well developed in the « Oriente » where they exhibit an unconformable and partly tectonic contact with the metamorphics. During the Jurassic, the Coastal Plain area was covered by thick accumulations of basic volcanic material which certainly extends eastwards and forms an integral part of the base to the western cordillera (Cordillera Occidental). The exact age of these volcanics, which are typical products of eugeosynclinal submarine effusions, is not known but they appear to be continuing until pre-Upper Cretaceous times. The Upper Cretaceous rocks are well developed over the entire country. Over the present Coastal Plain area, the rocks of this age are pyroclastics intercalated in a sequence of Maastrichtian marine sediments, in the Andean Range they are calcareous marine sediments, and in the « Oriente » region they are calcareous marine sediments at the base becoming gradually more detrital upwards until during the Palaeocene true continental deposits developed.

Exact demarcation between the Cretaceous and Tertiary is sometimes difficult and is either due to transitional phases, hiatuses, or fault contacts. Tectonic events were certainly important at this time and correspond to the Laramide Orogeny. Associated igneous activity is expressed by both andesitic volcanics and intrusives. The intrusives, of dioritic to granodioritic composition, are generally situated along both western and eastern foothill zones of the Andean cordilleras where they are controlled by north-south orientated structures. Granite appears to be extremely rare, but syenitic intrusions are described from the eastern foothills of the Cordillera Real in the north of the country. From deep drilling, Syenite has also been observed to underlie the Jurassic and Cretaceous sediments in the « Oriente » basin. Perhaps these syenites can be related to the Guyana Shield? It would appear from existing evidence that, at least in Ecuador, igneous activity associated with the Andean orogenies were characterized by a potash deficiency. The andesitic intrusives are rather complex and only detailed work will allow differentiation between older and younger andesites of similar genesis.

The Tertiary System is very well developed in Ecuador. Extremely thick sedimentary piles occupy the Coastal Plain area and fill the intra-Andean graben and the « Oriente » basin. Mixed and intercalated marine and continental sediments together with volcanic material typify the majority of Tertiary formations. Although the stratigraphy is somewhat complex, the principal common factor is that nearly all the detrital sediments were derived from the developing Andean Mountain ranges **(*)**.

(*) In the Manta area to the N.W. of Guayaquil, boulders of tourmaline-bearing granite have been observed in the Lower Tertiary sediments (Hoffstetter, 1956, p. 126; Goossens, 1968). These well-preserved boulders may have been derived from a now submerged East Pacific Ridge (Carnegie Ridge?).

The last phase of the Andean tectonic movements occurred in the late Tertiary, and is responsible for present Andean physiography. Intrusive and extrusive rocks related to this tectonic phase are quite important. Batholiths show a north-south alignment and are located near to the limits of the intra-Andean graben. The extrusives, which are often strongly pyroclastic in form, are characterized by an acidic to intermediate composition. Basaltic rocks appear to be extremely rare within the confines of the Andean Range, but information on this subject is still scarce. Related volcanic activity, which was initiated in the Pleistocene, is still continuing.

On the Coastal Plain the Quaternary is characterized by marine terraces near the coast. Inland, extensive black clay fluvial deposits give rise to fertile plains. In the« Oriente » many of the Tertiary and older sediments are obscured by thick Quaternary gravels of molassic character. Intra-montane piedmont and coarse pyroclastic deposits are typical in the Andean regions. The results of glacial and fluvio-glacial activity with their associated deposits are notable, particularly in the perched cordilleran valleys.

GENERAL STRUCTURE

The basic geological structure of Ecuador is characterized by major northerly and north-north-east striking normal faults of Tertiary to Recent age. Several reverse or low-angle thrust faults have been observed along the eastern slope of the eastern cordillera and also affect Tertiary sediments within the intra-Andean graben-controlled sedimentary basins. There is another important series of faults with an east-west orientation. Although recent movement may have occurred along these structures they are thought to be of Upper Cretaceous age or even older. They are sometimes associated with olivine-basalts which otherwise are not common. Although these east-west structures generally lack prominence because of later structural and volcanic activity, they are considered to form an extremely important part of pre-Andean and Andean tectonism. Their relation to metallogeny and economic mineral concentrations along the Andean belt is worthy of mention (Goossens, 1970a and b).

CONCLUSION (*)

The effect of Palaeozoic or even Precambrian orogenies is represented by the well-foliated metamorphics intruded by syenites and covered by late Palaeozoic sediments. These latter rocks have suffered partial and irregular metamorphism but to the east they generally remain unaltered. This complex is considered to represent the west and south-west extension of the Guyana and Brazilian Shields of which the Carnegie Ridge may represent the westernmost prolongation (Fig. 2a).

Although no information exists for the Permian and Triassic periods, a pre-Jurassic orogeny (*n* + 1) or tectonic phase accounted for a temporary separation of the present Coastal Plain and Amazon Basin areas possibly by an incipient ridge along the line of the present Andean chain. Throughout the Jurassic and a large part of the Cretaceous, submarine, often spilitic, lavas were deposited to the west of this « Mesozoic Ridge», whilst marine sediments were being deposited to the east in the area of the present « Oriente » or Amazon Basin (Fig. 2b).

It would appear that this incipient Andean ridge gradually disappeared by either progressive subsidence or erosion, as the Upper marine Cretaceous sediments apparently covered the entire country. In the Coastal Plain area these sediments are rich in volcanic material: an expression of the strong volcanic activity affecting the whole of this area throughout Jurassic and early Cretaceous times (Fig. 2c).

The boundary between the Cretaceous and the Tertiary is marked by strong tectonic movements corresponding to the Laramide Orogeny (*n* + 2). During this phase the entire country suffered uplift and the mountain chains were almost fully developed. In Ecuador, the two principal cordilleras («Occidental» or western and the «Real» or eastern) were formed, as was the central, intra-Andean graben. In the area of the Coastal Plain so-formed, a less important, coastal range was developed (represented by the still-prominent Cordilleras of Colonche and Chongón), whilst an incipient mountain range was developed in the « Oriente » region. In Colombia, to the north, this latter range is as important as the two principal Ecuadorian ranges, and is known locally as the Cordillera Oriental or Sierra Macarena (Gerth, 1955). A large graben, now occupied by the Babahoyo, Daule and Guayas river drainage systems, was developed between the Andean Cordillera Occidental and the coastal range (Guayaquil depression). The Laramide orogenic movements were accompanied by granodioritic-dioritic intrusions along the line of the principal north-south Andean faults. It is possible that this intrusive activity continued well into the Tertiary.

The Tertiary sea deposited marine shelf sediments intermixed with pyroclastic material over the graben area of the Coastal Plain, the summits of the coastal range mountains remaining as islands during this time. A similar process occurred east of the Andes in the Amazon Basin and foothills area. The intra-Andean graben were filled by pyroclastic and piedmont debris, and by lacustrine sediments in enclosed basin areas such as those of the Cuenca-Azogues region. Sediments of marine facies are rarely encountered in this area (Fig. 2d).

(*) This section represents an attempt to review the historical geology of the Ecuadorian territory.

Fig 2. Phases in Andean formation (in Ecuador)

a. LATE PALEOZOIC
Tectonic phase (*n* + 1): uplift of the actual Cordillera – the PREANDEAN RIDGE.
Note: one or more tectonic phases or orogenies (*n*) occurred before late Paleozoic.

b. JURASSIC TO MIDDLE CRETACEOUS
Note: the ANDEAN RIDGE disappears during the Mesozoic.

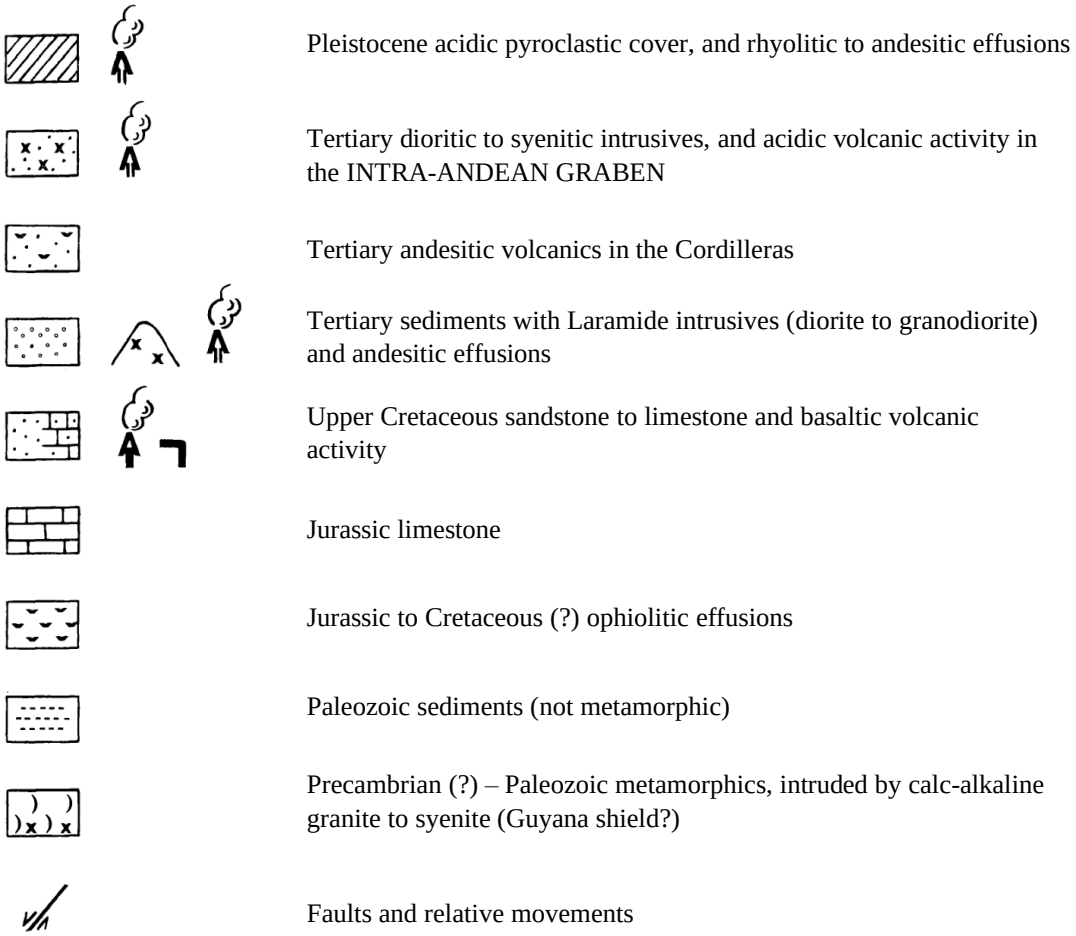
c. UPPER CRETACEOUS
Tectonic phase (Laramide) (*n* + 2)

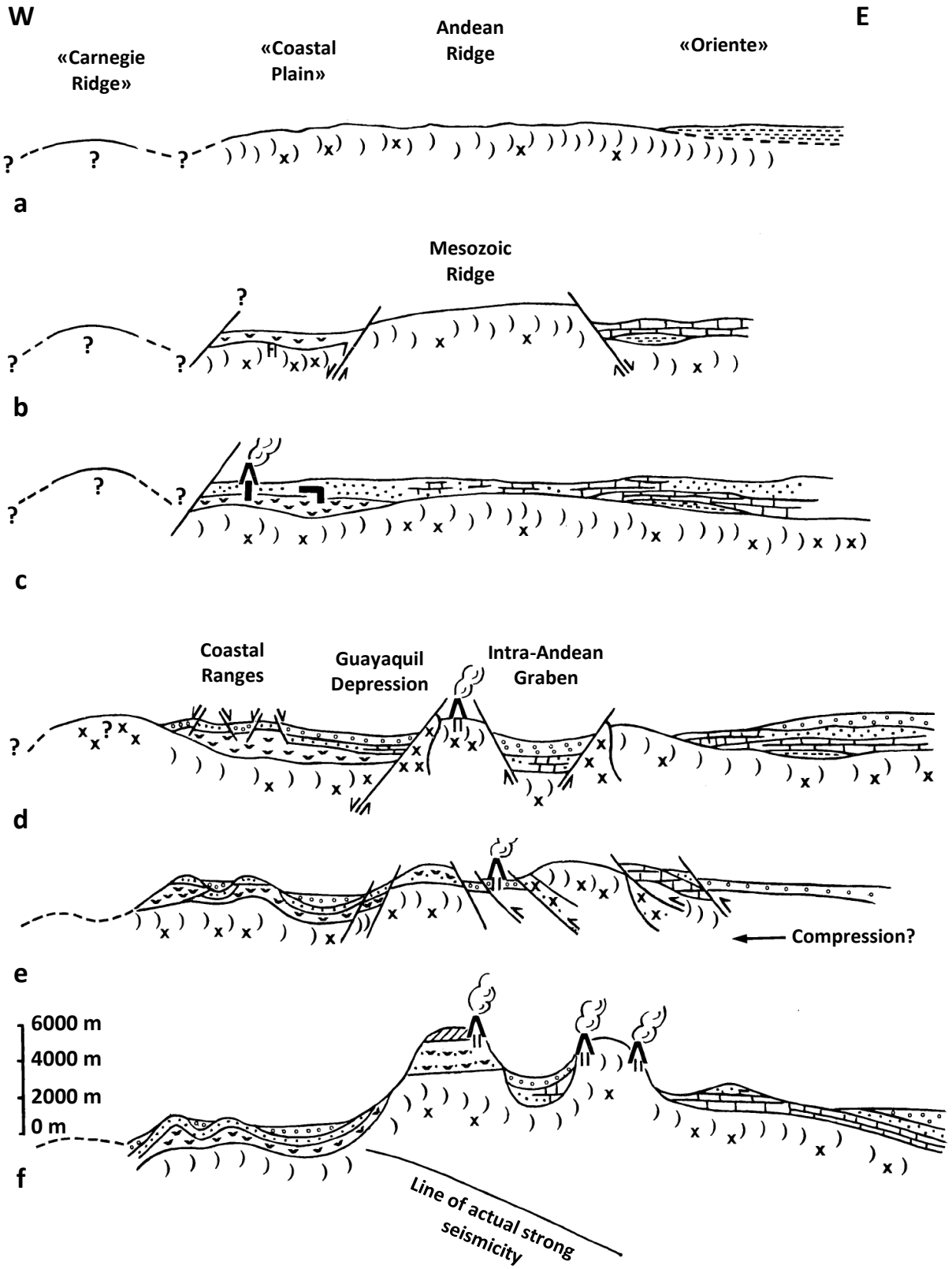
d. TERTIARY
Tectonic phase (*n* + 3) — Mio-Pliocene.

e. LATE TERTIARY
Tectonic phase (*n* + 4) — Pleistocene to Recent

f. CUATERNARY TO RECENT

LEGEND




W
E
«Carnegie Ridge»
«Coastal Plain»
Andean Ridge
«Oriente»
a
Mesozoic Ridge
b
c
Coastal Ranges
Guayaquil Depression
Intra-Andean Graben
d
Compression?
e
6000 m
4000 m
2000 m
0 m
Line of actual strong seismicity
f

An orogenic phase ($n + 3$) related to the Mio-Pliocene period principally affected the eastern part of the country and was characterized by the development of thrust-faults. This particular phase of tectonic activity was peculiar because of its tangential movements which were apparently caused by an emphasized east to west pressure (Fig. 2e). These tangential movements were directly followed during the Pleistocene by an important phase of uplift ($n + 4$) which affected the entire Andean belt and was important in developing the present-day morphology. These movements ($n + 4$) were accompanied by intense seismicity and volcanic activity which virtually blanketed the cordilleras with intermediate to acidic material and gave rise to the prominent volcanic masses over the northern half of the country. This volcanic phase, although at present somewhat dormant, is still continuing (Fig. 2f).

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